Heuristics and Meta-heuristics for some Constrained Spanning Tree Generation Problems

Synopsis of the Proposed Research Plan

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Research Proposal

Optimization deals with finding, for a given problem, the best of all feasible solutions. In a *discrete optimization problem*, the set of feasible solutions is finite. A combinatorial optimization problem (COP) is one in which the goal is to find (one or more) optimal solutions in a well-defined discrete problem space: a space comprising of a finite set of solutions that optimize a given objective function.

Combinatorial optimization problems occur in many areas of engineering and management (for instance, in the design and analysis of data networks, bridges, waterways; logistics for transportation, assignment, routing, facility location, finance, telecommunication network design, scheduling, manufacturing and so on, to mention a few).

Although the number of solutions to a COP is finite, it is typically exponential in terms of the input size. Exact algorithms for a COP do find optimal solutions on all instances of the problem within a bounded time, however, the high complexity of many combinatorial problems prohibits finding an exact solution in reasonable time.

In fact, most COPs are known to be NP-hard, which means that there is no known polynomial-time algorithm for solving them. Even when polynomial time algorithms exist for some problem, the degree of the polynomial is typically so large that solving realistic problem instances becomes infeasible. Clearly, in such situations, making use of exact algorithms to reach optimality may be impractical for all but very small problem instances, whereas approximate algorithms that concentrate on obtaining good feasible (but not necessarily optimal) solutions in much lesser time could be put to good use. A major focus in combinatorial optimization is therefore on the development of algorithms that provide a satisficing (not necessarily optimal) solution in reasonable time.

Spanning trees are useful for modelling COPs; they are very suitable for network design problems that involve finding a subset of edges of some graph G such that when these edges are removed from G the graph remains connected, and the sum of graph edges is minimal. They find application in a wide range of problem domains ranging from physical system design to cluster analysis.

Formally, given a connected, undirected graph G with non-negative edge weights, the Minimum Spanning Tree (MST) Problem aims to find a connected, acyclic sub-graph of G containing all the vertices of G (a *spanning tree* on G) such that the sum of all its edge weights is minimized. The problem is well known in graph theory and several algorithms exist that solve it in polynomial time. Several well-known algorithms extant in the literature solve this problem in polynomial time. However, constraints on the spanning trees often render the search for a lowest cost/weight tree much harder: constraining the problem with a bound on, for instance, the trees' degree, diameter or the number of leaves makes the problem NP-hard. Such constrained spanning tree generation problems occur in a wide range of application domains, such as VLSI routing, distributed mutual exclusion, information retrieval, data compression and content distribution network protocols.

A significant development in approximate algorithms is the emergence of a class of algorithms called *meta-heuristics*. Meta-heuristics incorporate various heuristic approaches into higher level frameworks that work with populations of (one or more) candidate solutions and try to improve these solutions by efficiently exploring the search space. Several meta-heuristic strategies like Simulated Annealing (SA), Evolutionary Algorithms (EAs) and Artificial Bee Colony (ABC) Optimization, to name a few, have been developed and applied successfully to a variety of optimization problems.

For several years now, the scope of performance improvements in single-core processors has been affected by semiconductor scaling limits and associated thermal issues and power requirements (the "Power Wall"), combined with the difficulty in exploiting greater levels of instruction level parallelism (the "ILP Wall"). This has led, over the past decade, to major developments in multi-core and many-core processor design, and the rise of programming models that take advantage of these parallel architectures.

A detailed literature study throws up many open issues, some of which are proposed to be addressed in the present work.